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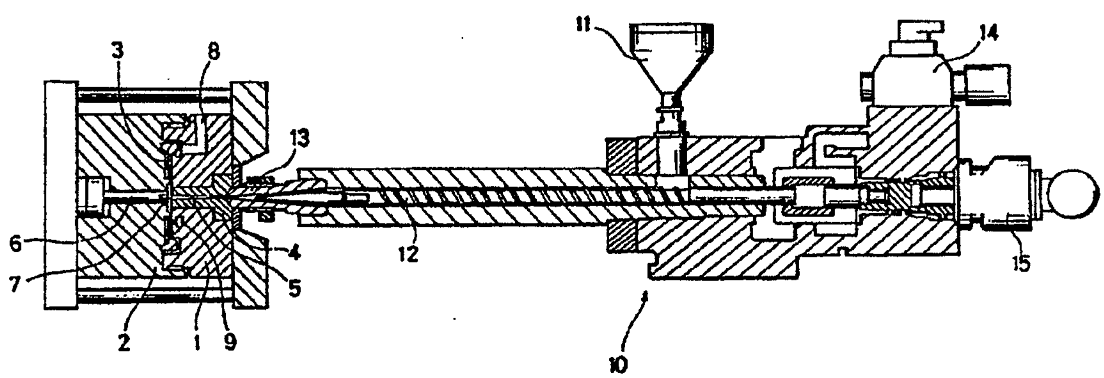
(54) **Injection moulding method using surge pressure.**

(57) A surge of high pressure is momentarily applied to a plasticized moulding material injected in a mould cavity (3) immediately after the completion of an injection process so that moulding shrinkage and orientation which are caused in the material in the mould cavity (3) in the course of solidification of the material on cooling can be substantially eliminated to thereby enable super-precision injection moulding.

FIG.1



EP 0 348 129 A2

INJECTION MOULDING METHOD USING SURGE PRESSURE

This invention relates to an injection moulding method using a surge pressure to be given to a moulding material injected into a mould cavity, and more particularly to an injection moulding method in which a surge of high pressure is momentarily applied to the plasticized resin material injected into the mould cavity immediately after the completion of a resin filling process so as to suppress moulding shrinkage and orientation of the resin material which occur in the course of solidification of the material, to thereby fulfil super-precision moulding.

Recently mass-storage memory media such as optical discs and audio compact discs are being increasingly put into practical use. It is undeniable that the development of precision plastic moulding techniques for moulding such optical discs makes a contribution to the practical application of high-density recording optical discs of high performance. For realization of high-density recording on the optical disc, it is essential to not only finish accurately the optical disc on the submicron order, but also achieve uniform optical characteristics of the optical disc.

Various methods have been developed for precisely moulding the high-density recording optical discs. For instance, the inventor of this invention has proposed a basic system for precise injection moulding by use of internal die pressure of a moulding resin material injected in a mold cavity (Japanese Patent Publication (B2) SHO 58(1983)-52486). In this conventional system, the internal die pressure is continuously monitored and controlled during injection moulding in accordance with reference pressure predetermined in a waveform pattern, to thereby produce remarkably precise moulded articles.

The inventor further proposed a high-speed injection moulding method on the basis of the aforesaid injection moulding system in European Patent No. EP 0096132 B1, in which a moulding material is injected in an injection mould under a high vacuum at an ultrahigh speed.

Now, in order to improve the moulding precision, moulding shrinkage which inevitably occurs in plasticized material injected in the mould cavity in the course of solidification of the material on cooling should be compensated thoroughly. In a compression moulding method, "dwelling" is often effected for compensation of the moulding shrinkage in the moulding material.

One of the compression moulding methods has been proposed in European Patent No. EP 0130769 B1, in which compression pressure to be applied to an injection mould is regulated with mould-clamping force while controlling internal die pressure of the plasticized resin material injected in the mould cavity in conformity with predetermined reference internal die pressure.

These conventional moulding methods, however, could not sufficiently respond to the strict requirements imposed on the precision moulding. That is, a technical system for thoroughly compensating the moulding shrinkage caused in the plasticized resin material on cooling as mentioned above has not been established so far.

To be more specific, the solidified part of the moulding material in the mould cavity spreads from the contact surface portion in touch with the inner surface defining the mould cavity toward the inside of the moulding material. The moulding material molten by heating progresses in solidification of the material even during a short period of resin filling and compression processes. That is to say, since solidification and shrinkage of the moulding material within the mould cavity have already started when the compression process has begun to apply compression pressure to the moulding material in the mould cavity by means of a mould clamping device, the moulding material which is being solidified on cooling is little influenced by the compression pressure after the filling process is finished. Thus, it is preferable to compress the moulding material in the mould cavity before the moulding material begins to solidify, whereas the application of the compression pressure before solidification of the material will give rise to back-flow of the moulding material to an injection part from which the moulding material is introduced into the mould cavity.

In addition, the conventional moulding methods cannot decrease the directional property resulting in "orientation" remained inside a finished moulding, which is caused by subjecting the composition of the moulding material to thermodynamic movement during moulding. The orientation in the finished moulding brings about unevenness in thickness and birefringence of the finished moulding. For instance, audio compact discs of 12 cm in diameter and 1.2 mm in thickness actually produced by a conventional injection moulding method have by and large an error of about 20 μm to 30 μm in thickness and are uneven in birefringence.

An object of this invention is to provide an injection moulding method capable of compensating moulding shrinkage in a plasticized moulding material injected in the mould cavity of an injection mould, which occurs in the course of solidification of the material on cooling, and suppressing orientation caused in the composition of the moulding material due to the directional property, to thereby enable super-precision

injection moulding.

To attain the above object according to this invention, there is provided an injection moulding method which comprises injecting a plasticized moulding material into a mould cavity of an injection mould under a high vacuum, and applying a surge pressure to the moulding material injected in the mould cavity within 0.01 to 0.05 second simultaneously with or immediately after the completion of injection of the moulding material into the mould cavity.

The time in which the surge pressure is applied and magnitude of the surge pressure are determined in accordance with various moulding conditions such as the injection speed, resin temperature and capacity of the mould cavity, so that internal stress due to application of the surge pressure is not remained in a finished moulding obtained resultantly.

By applying the surge pressure immediately after the completion of injection, variation of the finished moulding, such as unevenness in thickness and birefringence of the finished moulding can be effectively eliminated.

The features of the present invention which are believed to be novel are set forth with particularity in the appended claims. The present invention, both as to its organization and manner or operation, together with further objects and advantages thereof, may best be understood by reference to the following description, taken in conjunction wit the accompanying drawings.

The present invention will become more fully understood from the detailed description given hereinbelow and the accompanying drawings which are given by way of illustration only, and thus are not limitative of the present invention, and wherein:-

Figure 1 is a sectional side elevation schematically showing a typical example of an injection moulding machine to which the injection moulding method according to the present invention is applied;

Figure 2A through 2C are explanatory diagrams schematically illustrating a process in which an injection mould is actuated in moulding; and

Figure 3 is a diagram schematically showing a typical waveform pattern of internal die pressure.

The injection moulding method according to this invention will be described hereinafter with reference to Figure 1 illustrating an injection moulding machine for moulding audio compact discs by way of example.

The illustrated injection moulding machine comprises a set of stationary die plate 1 and movable die plate 2 between which a mould cavity 3 is formed, a sprue bush 4 having a sprue 5 and fitted in the stationary die plate 1, and a gate-cut pin 6 movably disposed opposite to the sprue bush 4 in the movable die plate 2. At the end portion open to the cavity 3 of the sprue 5 is formed a gate 7. A plasticized moulding material is injected into the mould cavity 3 through the sprue 5 and gate 7.

The stationary die plate 1 in this moulding machine is provided with a vacuum suction port 8 to which a vacuum pump (not shown) or the like is connected so as to evacuate the mould cavity 3 to a high vacuum of 10^{-1} Torr to 10^{-7} Torr in a resin filling process. The evacuation to a high vacuum effects to remove a skin layer composed of air or gas attached to the inner surface of the mould cavity 3.

At least one pressure sensor 9 for detecting the pressure (internal die pressure) of the moulding material $\underline{m}$ filled in the mould cavity 3 is disposed inside the stationary die plate 1 or movable die plate 2. Reference numeral 10 denotes an resin injection system for plasticizing and injecting the moulding material into the mould cavity 3 via the sprue 5 and gate 7. This injection system 10 comprises a hopper 11 for raw resin granules, a rotary screw 12 for advancing and injecting out of a nozzle head 13 the plasticized moulding material obtained by heating the raw resin granules, an injection servo mechanism 14 for regulating the internal die pressure of the moulding material filled in the mould cavity 3, and screw driving means 15 for driving the rotary screw 12.

The structure and elements of the injection moulding machine are generally known and therefore not described in detail here.

The internal die pressure of the moulding material in the mould cavity is detected by the pressure sensor 9 and controlled during the whole moulding process on the basis of a predetermined reference internal die pressure by means of the servo system including the servo mechanism 14. In Figure 3 shows one example of a waveform pattern of the internal die pressure actually detected from the moulding material in the mould cavity 3, which varies with time in conformity with the predetermined reference internal die pressure given in a waveform pattern.

In the waveform pattern illustrated, at the time t0 the injection system 10 starts to inject the plasticized moulding material $\underline{m}$ into the mould cavity 3. At the time t1 the mould cavity 3 is completely filled with the moulding material $\underline{m}$ introduced from the injection system 10. That is, the period t0-t1, which is designated as a filling process, is preferably on the order of 0.01 to 0.10 second. By injecting the moulding material into the mould cavity in such a short period of time at a high speed, a skin layer of the moulding material $\underline{m}$

which comes in face contact with the inner surface of the mould cavity 3 is not yet solidified entirely at the time of the completion of the filling process. The intermediate part of the moulding material m in the mould cavity is of course maintained in the molten state at that time. Thus, such a state that the moulding material in the mould cavity is not entirely solidified immediately after the filling process is finished can be accomplished by regulating the conditions such as the temperature of the moulding material and injection speed.

Then, at the time t1 a surge of high pressure is applied from the injection system 10 to the moulding material m in the mould cavity 3 within 0.01 to 0.05 second. That is to say, the surge pressure is momentarily given to the moulding material in the mould cavity 3 at a high speed simultaneously with or immediately after the moulding material is completely filled in the mould cavity. At the moment when the surge pressure reaches a maximum at the time t2, the application of the surge pressure is stopped (time t3).

The time t1-t2 for the application of the surge of high pressure depends on the moulding conditions such as the cavity capacity, i.e. the size of a finished moulded product resultantly obtained and the structure of the mould, whereas surge-application time of 0.01 to 0.10 second is permissible. In other words, the time in which the surge pressure is applied may be determined so that the surge pressure applied can be propagated to all the terminations of the material within the mould cavity, but not remained as internal stress in the finished moulded product.

Though the surge pressure Ps to be applied to the moulding material in the cavity varies with the moulding conditions such as the size of the finished product as described above, it is preferable to increase the surge pressure to the extent of slightly opening the closed mould against clamping force. To be concrete, the surge pressure 1.2 to 1.5 times the maximum filling pressure (specific injection pressure) Pf is effective. Though the maximum volume of the moulding material filled in the mould cavity when applying the surge pressure generally reaches approximately 120% of that in performing injection moulding according to a usual injection moulding method in which no such surge pressure is used, the volume of the moulding material may be determined to be just 100% when the surge pressure reaches a maximum.

The application of the surge pressure can be readily accomplished by use of a surge supplying system including the injection servo mechansim 14 capable of acting at a high speed and an injection mechanism with low inertia.

The foregoing processes comprise the resin filling process and the surge applying process which are effected within the time t0-t3 in Figure 3.

The application of the surge pressure is finished at t3 by suspending the surge supplying system and simultaneously thrusting the gate-cut pin 6 toward the sprue bush 4 to perform gate cutting as illustrated in Figure 2B. The gate cutting has an additional function of preventing an excess of injection pressure from flowing into the mould cavity and can be fulfilled by not only such gate cutting mechanism using the gate-cut pin 6 as illustrated, but also a restricted gate structure.

After the gate cutting as noted above, i.e. immediately after the time t3 in Figure 3, compression force may be exerted to the material in the mould cavity by momentarily moving the movable die plate 2 toward the stationary die plate 1 as shown in Figure 2C as performed in a usual compression moulding method.

From the time t3 at which the gate cutting is perfomed, the moulding material in the mould cavity begins to solidify on cooling to rapidly reduce the internal die pressure of the material. As indicated by the chain line d in Figure 3, dwelling may be effected after the gate cutting as in the compression moulding method. That is to say, in a dwelling process, the internal die pressure is maintained by operating a clamping mechanism for exerting the clamping force to the moulding material in the mould cavity at a pressure nearly equal to the filling pressure (injection pressure) Pf.

As described above, by applying the surge of high pressure to the moulding material injected in the mould cavity immediately after the completion of a resin filling process, occurrence of moulding shrinkage and orientation of the resin material can be prevented.

Next one example of producing a 12 cm diameter and 1.2 mm thick audio compact disc of polycarbonate plastic by the moulding method using a surge of high pressure will be described. When the audio compact discs are moulded under conditions of injection time t0-t1 of 0.10 second, surge supplying time t1-t2 of 0.50 second, and maximum surge pressure Ps of about 300 kg/cm^2, the following average is obtained as the result of measurement.

Birefringence:	10 to 15 nm
Variation in thickness:	5 µm

Compared with the conventional moulding method without using a surge pressure in which average variation in thickness of the compact discs resultantly produced has been more than 20 µm, moulding precision is far improved according to the present invention. Besides, the birefringence of the compact disc produced by the method of this invention is decreased to the extent that it can be neglected in an optical system and considered to be substantially uniform.

As is clear from the foregoing, in accordance with the present invention, moulding shrinkage and orientation caused in a moulding material within a mould cavity in the course of solidification of the material can be eliminated substantially to perfection by applying a surge of high pressure to the material in the mould cavity within 0.01 to 0.05 second simultaneously with or immediately after the completion of injection of the material into the mould cavity. Accordingly, super-precision injection moulding of high performance can be fulfilled and provide remarkably high reproductivity of end-products, wit the result that not only various types of optical elements such as optical recording discs and optical lenses, but also micro-mechanical parts having super-fine structure can be moulded with high accuracy.

Obviously many modifications and variations of the present invention are possible in the light of the above teachings. It is therefore to be understood that within the scope of the appended claims in the invention may be practiced otherwise than as specifically described.

Claims

1. An injection moulding method comprising injecting a plasticized moulding material into a mould cavity (3) of an injection mould under a high vacuum, applying a surge pressure to the moulding material injected in said mould cavity (3) within 0.01 to 0.05 second simultaneously with or immediately after the completion of the injection of the moulding material into said mould cavity, and effecting gate cutting immediately after the application of the surge pressure.

2. An injection moulding method according to claim 1 wherein the surge pressure is 1.2 to 1.5 times an injection pressure at which the moulding material is injected into said mould cavity (3).

3. An injection moulding method according to claim 1 wherein the surge pressure is about 300 kg/cm^2 at a maximum.

4. An injection moulding method according to claim 1 wherein a compression pressure is applied to the moulding material in said mould cavity (3) immediately after the gate cutting.

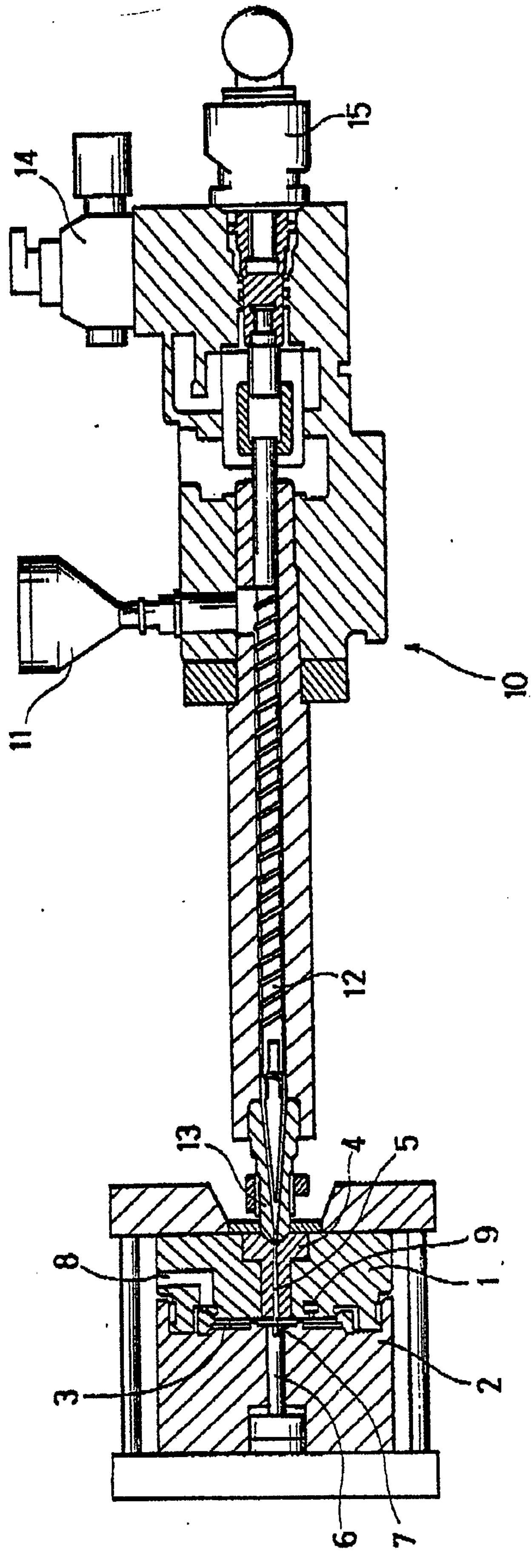
5. An injection moulding method according to claim 1 wherein a compression pressure is applied to the moulding material in said mould cavity (3) immediately after the gate cutting and thereafter maintained in a dwelling process.

6. An injection moulding method comprising evacuating a mould cavity (3) in an injection mould to a high vacuum of 10^{-1} Torr to 10^{-7} Torr, injecting a plasticized moulding material into said mould cavity (3), momentarily applying a surge pressure 1.2 to 1.5 times an injection pressure at which the moulding material is injected into said mould cavity (3) to the moulding material injected in said mould cavity within 0.01 to 0.05 second simultaneously with or immediately after the completion of the injection of the moulding material into said mould cavity, and effecting gate cutting immadiately after the application of the surge pressure.

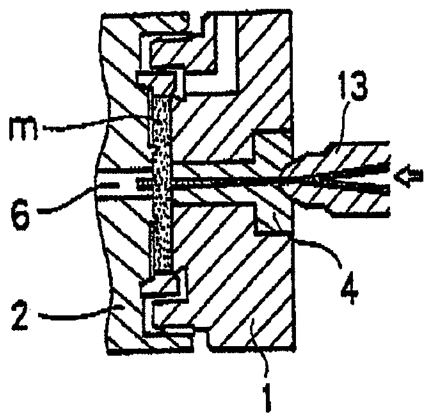
7. An injection moulding method according to claim 6 wherein the moulding material is injected into said mould cavity (3) in accordance with a predetermined internal die pressure given in a waveform pattern.

8. An injection moulding method comprising evacuating a mould cavity (3) inside an injection mould to a high vacuum of 10^{-1} Torr to 10^{-7} Torr, injecting a plasticized moulding material into said mould cavity (3) in accordance with a predetermined internal die pressure given in a waveform pattern, momentarily applying a surge pressure 1.2 to 1.5 times an injection pressure at which the moulding material is injected into said mould cavity to the moulding material injected in said mould cavity within 0.01 to 0.05 second simultaneously with or immediately after the completion of the injection of the moulding material into said mould cavity so as to prevent the moulding material in said mould cavity from solidifying except for a skin layer in touch with an inner surface of said mould cavity, and effecting gate cutting immediately after the application of the surge pressure.

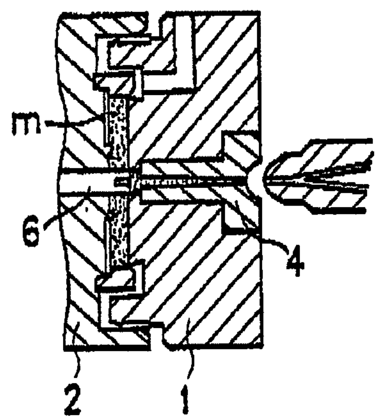
FIG.1



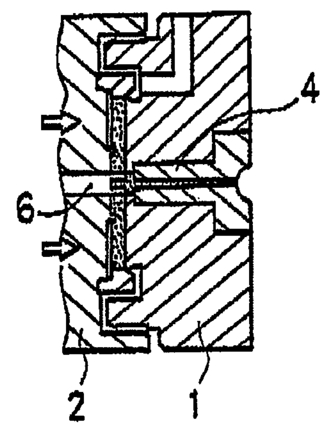
F I G. 2A



F I G. 2B



F I G. 2C



F I G. 3